

A better understanding of the production and delivery of fine-grained suspended sediment is obtained from expressing transport as load per unit area (yield). Notwithstanding the 37 T/y/km² indicated from the headwaters station on Ward Creek (10336670) with only three years of record, it is the index stations representing disturbed streams that produce the most fine-grained sediment (Table 3-10). In descending order, they are: Blackwood (21.5 T/y/km²), Third (20.2 T/y/km²), and Ward Creeks (16.4 T/y/km²). On average, the Upper Truckee River produces about as much fine-grained sediment per unit area as does Incline Creek, about 7 T/y/km². The effect of disturbances on fine-grained sediment production is evident by comparing yield values from relatively undisturbed western streams such as General, Meeks, and Eagle Creeks with those from Blackwood and Ward Creeks. On average the disturbed western watersheds produce about 10 times more silt and clay per unit area than the undisturbed basins (Table 3-10; Figure 3-11).

On the eastern side of the lake median, annual fine-grained suspended-sediment yields range from 0.4 T/y/km² from the undisturbed Logan House watershed to 1.4 T/y/km² in the developed Edgewood Creek watershed, a difference of three and one-half times. Data on yields from the north quadrant are limited to Third and Incline Creeks with Incline producing substantially less silt and clay per unit area than Third. Given the similar degrees of disturbance in these two watersheds, the difference is probably due to more intense erosion processes in the higher elevations of the Third Creek watershed.

3.7 Intra-Basin Variations

Several watersheds including Edgewood, Incline, Trout and Ward Creeks, and the Upper Truckee River contain more than one sampling station and thereby provide a mechanism to compare sediment production from different parts of each watershed (Table 3-11). With the exception of Edgewood and Trout Creeks, median-annual concentrations are greatest at the downstream-most locations of the five watersheds indicating progressively more sediment being entrained from channel sources. Lower yields in the downstream direction along Edgewood and Trout Creeks indicate sediment storage in channels or retention ponds and lakes. Time-series cross sections along Edgewood Creek show average net deposition of about 14 m³/y/km (1984-2002) along 5.6 km of channels. In addition, sediment retention ponds below the downstream-most station on Edgewood Creek provide additional opportunities to reduce sediment loads before waters enter the lake. Trout Creek contains a small lake between stations 10336780 and 10336790 that traps sediment.

Suspended-sediment loads per unit of runoff increase in the downstream direction along Incline Creek and the Upper Truckee River with sediment entrained from eroding streambanks (Table 3-11). Along the Upper Truckee River this is particularly evident in the sinuous reach adjacent to the golf course where about 650 m³/y/km of bank materials has been eroded over 2.9 km between 1992 and 2002. That median annual concentrations for the upstream-most stations on Trout Creek and the Upper Truckee River are the same (7.8 g/m³) is certainly coincidental, yet sediment-transport rates past these two “reference” stations are probably indicative of background rates of sediment production from predominantly forested upland sources in the southern quadrant of the basin.

The exceptionally high median-annual concentration from the upstream-most site on Ward Creek (Table 3-11) agrees with the observations of Reuter and Miller (2000) and Stubblefield (2002) that the badland area in the unvegetated headwaters contributes large quantities of sediment to the main stem where suspended-sediment transport is greatly reduced. However, results for this site (10336670) are based on only three years of record. Suspended-sediment transport increases again in the lower-most reaches with material entrained from eroding streambanks.

Results presented in this section and in Table 3-11 are in general agreement with the narrative on the subject by Reuter and Miller (2000) with the exception of the interpretation about the downstream-most reaches of Ward Creek. Figure 3-11 showing median annual suspended-sediment yields of fine-grained materials is useful in visualizing the trends discussed above.

Table 3-11. Median annual suspended-sediment concentrations for stations along five Lake Tahoe streams. All data expressed in grams of sediment per cubic meter of water (annual concentration). Numbers in parentheses are percent change from next station upstream.

Location	Stream and (Quadrant)				
	Edgewood (E)	Incline (N)	Ward (W)	Trout (S)	Upper Truckee (S)
Upstream	6.50	16.7	83.4 ¹	7.8	7.8
Mid-basin 1		22.7 (36)	16.8 (-80)	10.7 (37)	15.4 (97)
Mid-basin 2	12.6 (94)		15.5 (-8)	41.2 (285)	
Downstream	6.94 (-45)	29.4 (30)	30.7 (98)	15.0 (-64)	27.1 (76)

¹ = Only three complete years of data.

3.8 Suspended-Sediment Transport from “Reference” and Disturbed Watersheds

Concerns over the role of development and other forms of human-induced disturbances on the delivery of suspended-sediment to Lake Tahoe has been justified on the basis of studies such as those by Glancy (1988) and others documenting the erosion problems associated with these practices. Because of differences in rainfall-runoff characteristics, surficial geology, and land cover, stable, undisturbed watersheds located in the different basin quadrants are likely to have varied sediment-transport regimes.

To differentiate between “background” and “impacted” suspended-sediment loadings from for each of the four basin quadrants, “reference” stations or watersheds are selected. This procedure allows for comparison between relatively undisturbed watersheds and those that have been disturbed or altered by human intervention. Considerations in selecting these reference stations include length of flow and sediment record, amount of channel and watershed

disturbance, and comparable drainage areas to the disturbed sites in the quadrant. Reference stations are shown in Table 3-12.

Table 3-12. Reference stations selected for each of the four basin quadrants.

Basin quadrant	Stream	Station number	% Basin with high potential upland erosion¹	Length of record (years)	Drainage area (km²)
North	Incline	103366993	3.1	10	7.2
South	Upper Truckee	10336580	18.0	10	36.5
East	Logan House	10336740	0.0	17	5.4
West	General	10336645	1.8	20	19.3

¹ Methods and analysis described in Chapter 6.

Suspended-sediment yields per unit area from disturbed western streams Ward and Blackwood Creeks are 275% to 630% greater respectively, on an annual basis than the “reference” General Creek watershed. These values are comparable to those expressed in terms of yield per unit of runoff (g/m³; Table 3-8). In the Upper Truckee River watershed, yields per unit area are roughly 75% greater in the flatter alluvial sections where bank erosion is active than at the upstream “reference” station. When compared in terms of median annual concentrations, the disturbed reaches of the Upper Truckee River pass about 250% more sediment per unit of runoff than reaches not experiencing bank erosion. In the eastern quadrant, the index station on Edgewood Creek passes about 330% more suspended-sediment per unit area (about 100% more per unit of water) than does the index station on Logan House Creek.

Comparisons in the north quadrant are difficult given that development in this part of the Lake Tahoe watershed has impacted most of the tributary streams draining the lake. The very high erosion rates from parts of the high elevation areas of Third Creek and comparisons between “reference” and representative, disturbed stations provide additional uncertainty. Still, the upstream-most site on Incline Creek (103366993) is considered a reference because it contains about half the density of unpaved roads compared to the area containing the index stations for Third and Incline Creeks, and few paved roads. Suspended-sediment yields per unit of runoff do show considerable differences with the index sites on Incline (73% greater) and Third Creeks (about 800% greater) that encompass more of the developed area.

3.9 Temporal Trends in Suspended-Sediment Delivery to Lake Tahoe

One of the most critical issues concerning degradation or recovery of Lake Tahoe water clarity is the question as to whether suspended-sediment loads are changing over time, and consequently, are restoration and erosion control efforts effective. Analysis of the temporal variations in sediment delivery to Lake Tahoe are based on the fundamental assumption that precipitation characteristics over the past 40 years have not changed substantially beyond the stochastic variations inherent in runoff production. Because temporal variations in annual suspended-sediment loads are dominated by annual changes in runoff, loads expressed per unit

of runoff is a particularly sensitive parameter to interpret temporal trends. Three techniques were used with statistical testing to evaluate temporal trends in the hope of developing parallel lines of evidence. They are:

- (1) Annual variations in suspended-sediment loads per unit of runoff;
- (2) Daily variations in suspended-sediment loads per unit of runoff; and
- (3) Decadal (or less) shifts in the slope and intercept of suspended-sediment transport ratings.

The first two techniques were utilized where there was sufficient mean-daily flow data to calculate annual values for a minimum of five years. The third technique was used where there was no mean-daily flow data but only instantaneous values to develop sediment-transport ratings.

Annual suspended-sediment loads for 21 stations were divided by the total runoff for each year of record and plotted with time to obtain temporal trends of annual concentrations. Examples from ten index stations are shown in Figure 3-12. Statistical analysis of the data shown in Figure 3-12 and for the other 11 stations were conducted to determine the existence of any trends with time. Results of linear regression analysis are displayed in Table 3-13. Only three sites indicating decreasing annual loads have relations significant at the 0.10 level of significance: Upper Truckee River (10336610), Third Creek (10336698), and Trout Creek (10336790). Results for the latter site may be questionable in that there are only 5 years of flow record. In general the results listed in Table 3-13 are not particularly enlightening with extremely low r^2 values, indicating that very little if any of the variation in loads with time is explained. In an attempt to improve statistical significance and provide more reliable results, the analysis was recast using daily values to increase the number of observations (n).

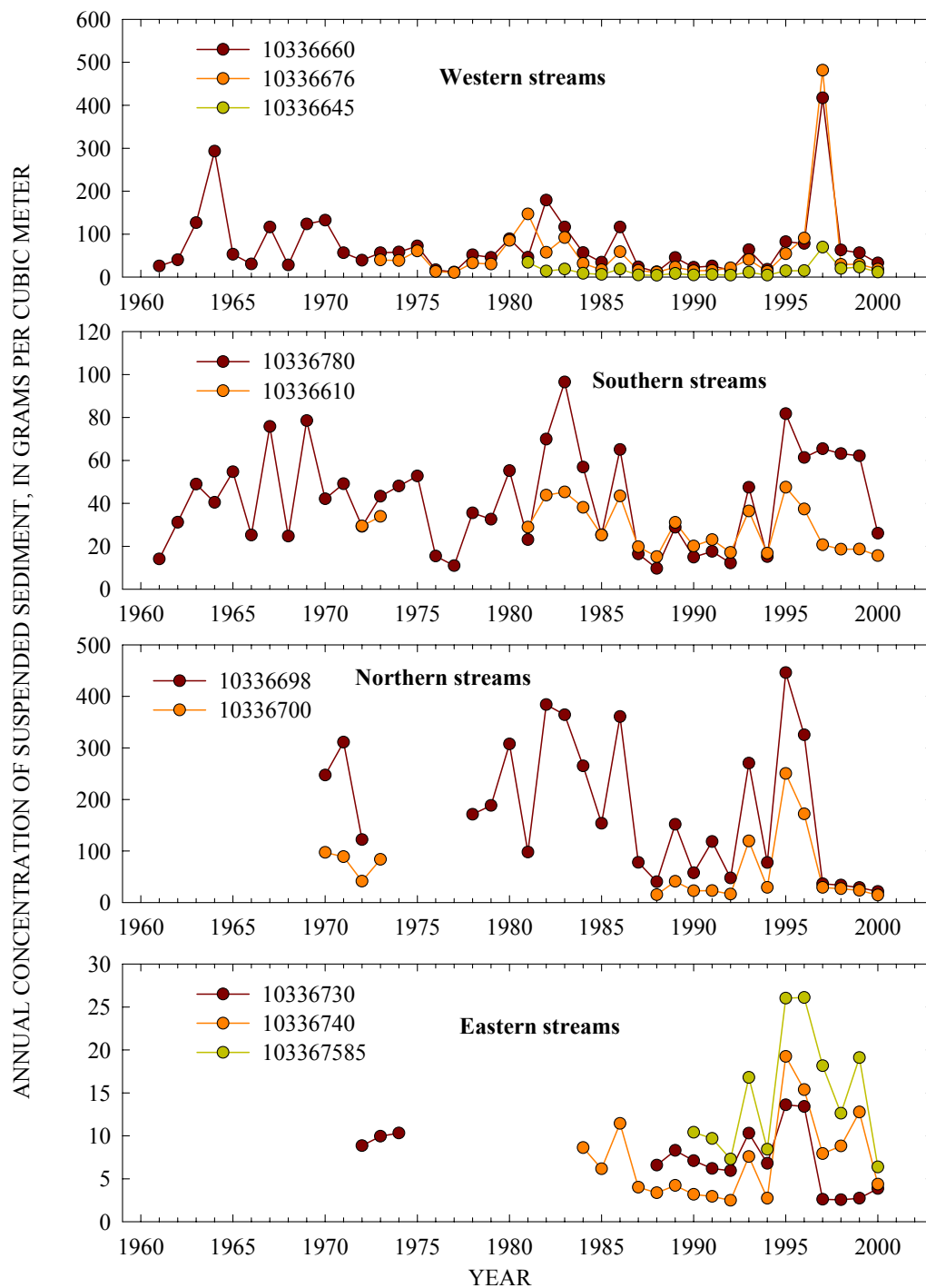


Figure 3-12. Annual concentrations of suspended sediment obtained by dividing annual suspended-sediment load by annual runoff.

Table 3-13. Summary statistics of analysis of temporal trends in annual concentration (in g/m³).

Stream	Station	Equation	r ²	F-value	P-value	n	Significance and trend
Blackwood	10336660	y=347-0.12x	.0004	0.02	0.90	40	none
General	10336645	y=-907+0.46x	0.03	0.62	0.44	20	none
Ward	10336674	y=92.9-0.04x	.00015	.0009	0.98	8	none
Ward	10336675	y=-1082+0.55x	0.02	0.14	0.72	9	none
Ward	10336676	y=-3733+1.91x	0.03	0.83	0.37	28	none
Trout	10336770	y=298-0.14x	.0018	0.01	0.91	10	none
Trout	10336775	y=-171+0.09x	.0010	0.01	0.93	10	none
Trout	10336780	y=-150+0.10x	.0025	0.10	0.76	40	none
Trout	10336790	y=765-0.38x	0.67	6.21	0.09	5	some (-)
UTR	10336580	y=-330+0.17x	0.01	0.11	0.75	10	none
UTR	10336610	y=1071-0.52x	0.14	3.32	0.08	22	some (-)
UTR	103366092	y=-936+0.48x	0.03	0.26	0.62	10	none
Incline	10336700	y=1055-0.50x	0.01	0.10	0.76	17	none
Incline	103366993	y=-1331+0.67x	0.08	0.72	0.42	10	none
Incline	103366995	y=-3361+1.70x	0.12	1.08	0.33	10	none
Third	10336698	y=10807-5.35x	0.12	3.40	0.08	26	some (-)
Eagle Rock	103367592	y=-727+0.37x	0.18	1.73	0.22	10	none
Edgewood	10336760	y=189-0.09x	0.01	0.06	0.81	8	none
Edgewood	103367585	y=-962+0.49x	0.05	0.50	0.50	11	none
Glenbrook	10336730	y=317-0.16x	0.16	2.74	0.12	16	none
Logan House	10336740	y=-544+0.28x	0.08	1.33	0.27	17	none

Results using daily values show all but five sites with statistically significant trends of decreasing daily concentrations (based on the P-value of the regression) but the results are still considered suspect because of the exceedingly flat slopes indicated by the regression equation (Table 3-14). Although P-values suggest that the slope of the majority of regressions is significantly different than zero (flat, with no trend) this can be largely attributed to the very large sample size. Note the very low slopes of the regressions listed in Table 3-14. Restated, if any trend with time existed, it would show up in the analysis of daily values. That five sites still showed no statistically significant trend is important. These five locations all represent upstream and, or reference sites in the watershed and would, therefore, not be expected to display attenuation of sediment- transport rates in response to disturbance.

Table 3-14. Summary statistics of analysis of temporal trends in mean-daily concentrations (in g/m³). Stations highlighted in pale yellow signify no discernable trend.

Stream	Station	Equation	r ²	F-value	P-value	n	Significance and trend
Blackwood	10336660	y=18.5-1.74e-4x	.0003	4.75	0.03	14975	definite (-)
General	10336645	y=4.33+7.43e-5x	.0003	2.39	0.12	7756	none
Ward	10336674	y=6.76-7.83e-4x	.006	20.5	0.0001	3652	definite (-)
Ward	10336675	y=6.45-3.47e-4x	.001	4.55	0.03	3653	definite (-)
Ward	10336676	y=14.0-3.84e-4x	.0009	9.41	0.0022	10592	definite (-)
Trout	10336770	y=5.54-2.42e-4x	.001	5.71	0.02	4150	definite (-)

Trout	10336775	$y=619-8.87e-5x$	.0002	0.94	0.33	4140	none
Trout	10336780	$y=25.0+1.51e-4x$	.0007	11.0	0.0009	14975	definite (+)
Trout	10336790	$y=15.1-3.35e-3x$	0.15	465	0.0001	2557	definite (-)
UTR	10336580	$y=2.86-7.05e-5x$	.004	1.77	0.18	4160	none
UTR	10336610	$y=19.4-8.00e-4x$	0.03	299	0.0001	9526	definite (-)
UTR	103366092	$y=4.20-2.21e-4x$	.001	5.55	0.02	4140	definite (-)
Incline	10336700	$y=51.7-3.44e-3x$	0.01	90.5	0.0001	6839	definite (-)
Incline	103366993	$y=8.04-2.93e-4x$	.002	6.96	0.01	4171	definite (-)
Incline	103366995	$y=18.0-1.08e-3x$	.009	37.3	0.0001	4295	definite (-)
Third	10336698	$y=128-7.75e-3x$	0.04	376	0.0001	10469	definite (-)
Eagle Rock	103367592	$y=5.23+7.96e-4x$	0.11	469	0.0001	3970	definite (+)
Edgewood	10336760	$y=5.34-3.61e-5x$	.00002	0.49	0.49	3287	none
Edgewood	103367585	$y=10.2-2.54e-4x$	.001	5.96	0.01	4383	definite (-)
Glenbrook	10336730	$y=8.07-5.27e-4x$	0.11	769	.0001	6529	definite (-)
Logan House	10336740	$y=4.28+1.75e-6x$	5.70E-07	0.004	0.95	6575	none

By using a combination of statistical measures from Table 3-14, we can perhaps extract additional useful information from the analysis. Arbitrarily setting stricter limits on the Type III sum of squares measure (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, we can discriminate the following five sites as having significant temporal trends of sediment-transport rates:

- (1) Upper Truckee River, 10336610 (decreasing);
- (2) Incline Creek, 10336700 (decreasing);
- (3) Third Creek, 10336698 (decreasing);
- (4) Glenbrook Creek, 10336730 (decreasing); and
- (5) Eagle Rock Creek, 103367592 (increasing).

The watersheds draining all of these stations have experienced some level of disturbance over the past 40 years and the data indicate that the first four are recovering due to a combination of natural adjustment processes and erosion-control measures. The same cannot be stated conclusively for Ward and Blackwood Creeks where sediment-transport rates remain high. There is no statistical evidence from either the annual or daily analyses that index stations from the three main western streams (Blackwood, Ward, and General Creeks) have increasing rates of sediment transport as reported by Rowe *et al.* (2002). However, negative slopes of the regression equations (indicating the rate of decreasing sediment transport) are greatest for Incline and Third Creeks reflecting more rapid attenuation of transport rates.

3.9.1 Temporal Trends in Fine-Grained Loadings

Statistical analysis identical to that performed for total annual and total mean-daily suspended-sediment loads were carried out for the available fine-loads data. As expected, the analysis of temporal trends in annual, median concentrations of fine-grained suspended sediment mirrors that of total, annual with the Upper Truckee River and Third and Glenbrook Creeks displaying a significant decreasing trend of concentrations (Table 3-15). Aside from the downstream-most station on Trout Creek (10336790) which represents a short period of record, and therefore, a questionable trend, the remaining sites show no discernable trend in annual

concentrations. Although two of the western streams (Ward and General Creeks) have positive regression slopes, neither of these relations are significant.

Table 3-15. Summary of statistical analysis of temporal trends in fine-grained median, annual concentrations of suspended sediment (in g/m³).

Stream	Station	Equation	r ²	F-value	P-value	n	Significance
Blackwood	10336660	y=105-0.04x	.0001	0.005	0.94	40	none
Ward	10336676	y=-770+0.40x	0.02	0.48	0.50	28	none
General	10336645	y=-164+0.09x	0.05	0.87	0.36	20	none
UTR	10336610	y=443-0.22x	0.22	5.53	0.03	22	definite (-)
Trout	10336790	y=-50.3+0.03x	0.71	7.43	0.07	5	some (+)
Trout	10336780	y=-22.3+0.02x	0.001	0.05	0.81	40	none
Third	10336698	y=3206-1.59x	0.24	7.58	0.01	26	definite (-)
Incline	10336700	y=1508-0.74x	0.07	1.04	0.33	17	none
Incline	103366995	y=280-0.13x	.009	0.07	0.79	10	none
Incline	103366993	y=-3553+1.8x	0.09	0.82	0.39	10	none
Edgewood	103367585	y=294-0.14x	0.02	0.20	0.67	11	none
Glenbrook	10336730	y=251-0.12x	0.19	3.23	0.09	16	some (-)
Logan House	10336740	y=-154+0.08x	0.03	0.43	0.52	17	none

If we retain the stricter statistical limits on the Type I sum of squares measure used previously (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, the following sites as having significant trends of fine-grained suspended-sediment transport rates (Table 3-16):

- (1) Upper Truckee River, 10336610 (decreasing);
- (2) All of the sites on Incline Creek, (decreasing);
- (3) Third Creek, 10336698 (decreasing);
- (4) Glenbrook Creek, 10336730 (decreasing); and
- (5) Edgewood Creek, 103367592 (increasing).

There is again, no indication of increasing sediment-transport rates from the western quadrant streams.

Table 3-16. Summary of statistical analysis of temporal trends in fine-grained daily concentrations of suspended sediment (in g/m³).

Stream	Station	Equation	r ²	F-value	P-value	n	Significance
Blackwood	10336660	y=11.6-1.30e-4x	.001	15.4	.0001	14975	definite (-)
Ward	10336676	y=9.07-3.09e-4x	.006	64.0	.0001	10592	definite (-)
General	10336645	y=3.26-3.24e-5x	.0003	14.6	.0001	7756	definite (-)
UTR	10336610	y=10.4-3.90e-4x	0.05	544	.0001	9526	definite (-)
Trout	10336790	y=6.10+5.69e-5x	.0026	465	.0099	2557	definite (+)
Trout	10336780	y=11.0+3.34e-5x	.0007	7.22	.007	14975	definite (+)
Third	10336698	y=127-7.68e-3x	0.03	369	.0001	10469	definite (-)

Incline	10336700	$y=34.0-2.85e-3x$	0.04	264	.0001	6839	definite (-)
Incline	103366995	$y=13.4-1.66e-3x$	0.17	893	.0001	4295	definite (-)
Incline	103366993	$y=4.69-5.37e-4x$	0.08	351	.0001	4171	definite (-)
Edgewood	103367585	$y=8.47-8.48e-4x$	0.07	346	.0001	4383	definite (-)
Glenbrook	10336730	$y=42.3-9.01e-4x$	.0003	2.14	0.14	6529	none
Logan House	10336740	$y=4.28-8.15e-5x$	.0048	30.9	.0001	6575	definite (-)

3.9.2 Shifts in Suspended-Sediment Transport Ratings

The third line of evidence used to interpret temporal trends in sediment delivery to Lake Tahoe is an analysis of shifts in the sediment-transport rating relations. Mean-daily or annual data are not required for this analysis, only a series of statistical tests to determine whether the relation between instantaneous discharge and instantaneous suspended-sediment concentration is changing with time. An example using data from Third Creek is shown in Figure 3-13.

Regression data from at least three periods for northern quadrant streams (Third, Incline, and Wood Creeks) are provided as an example of this technique. Table 3-17 shows both generally decreasing intercepts (load at $1 \text{ m}^3/\text{s}$) and exponents (rate of increase of load with increasing discharge) for the three streams. This is indicative of trends towards lower production of suspended-sediment and is supported by Type I and Type III sum of squares (SS) tests shown in Table 3-18. The Type I SS tests whether the slope of the rating is different than 0.0. The Type III SS tests whether the slopes or intercepts of the ratings are significantly different from one another. The decision matrix is shown in Table 3-18 for five stations on four northern streams with the conclusion that these streams are experiencing reductions in sediment loads across the range of discharges (Figures 3-13 and 3-14a). Particular attention is given to the northern quadrant because of published accounts of historically high suspended-sediment loads.

Results for Blackwood Creek (10336660), although statistically significant are extremely subtle in comparison to the northern quadrant (Figure 3-14b). The same can be said for the Upper Truckee River index station (10336610) where suspended-sediment loads over the range of discharges first increased during the 1983-1992 period but then decreased during the 1993-2002 period to values below the 1972-1982 period. Ward Creek, the other large sediment contributor also does not show conclusive evidence that loads are decreasing across the range of flows over the entire period, particularly at high discharges. Results for Blackwood and Ward Creeks, and the Upper Truckee River indicating lower suspended-sediment loads during the period 1993-2002 probably reflect the enormous flushing of stored sediment that took place during the January 1997 event.

Table 3-17. Comparison of suspended-sediment transport ratings for different periods for index stations on three north quadrant streams.

Stream	Period	Intercept	Exponent	n
Third	1965-1974	103	2.84	248
	1975-1984	18.3	2.02	74
	1985-1994	46.7	2.05	235
	1995-2002	6.3	2.10	267

Incline	1965-1974	85.9	2.51	229
	1975-1984	no data	no data	-
	1985-1994	18.4	2.12	224
	1995-2002	5.0	2.09	203
Wood	1969-1970	967	2.76	50
	1991-1996	69.5	1.96	54
	1997-2002	31.2	2.22	40

Table 3-18. Decision matrix using Type I and III sum of squares tests to determine if shifts in suspended-sediment transport ratings are statistically significant for four northern quadrant streams.

Stream	Station	Sum of Squares Test	Testing	F - value	P- value	Result	Conclusion
First	10336688	Type I	slope = 0	141	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	6.55	.0003	Slopes are not equal	Ratings are not = and not parallel
		Type III	Intercepts =	26.8	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Wood	10336692	Type I	slope = 0	189	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	5.65	0.0043	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	36.8	<.0001	Intercepts are not equal	Ratings shift (-)
Third	10336698	Type I	slope = 0	489	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.49	0.215	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	185	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Incline	10336700	Type I	slope = 0	514	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	4.61	0.0102	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	260	<.0001	Intercepts are not equal	Ratings shift (-)
Incline	103366995	Type I	slope = 0	298	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.72	.1816	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	53.5	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)

Convincing evidence of reductions in sediment-transport rates is also available from this analysis for the index station on Edgewood Creek (1093367585), showing parallel shifts to lower suspended-sediment loads significant at the 0.0001 level.

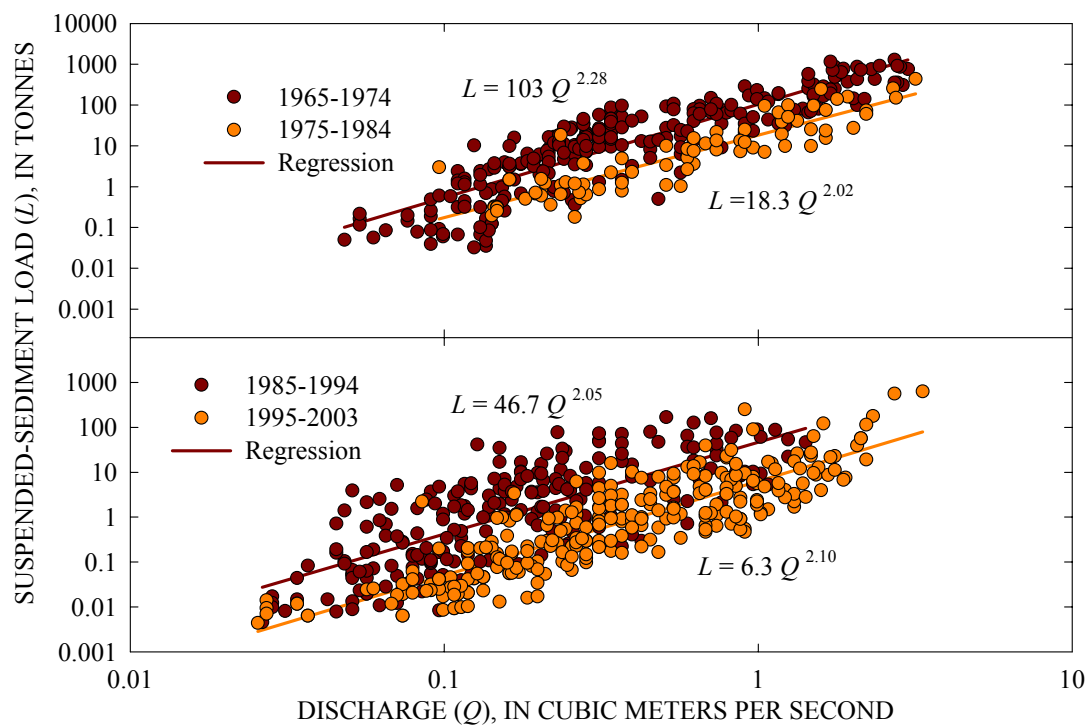
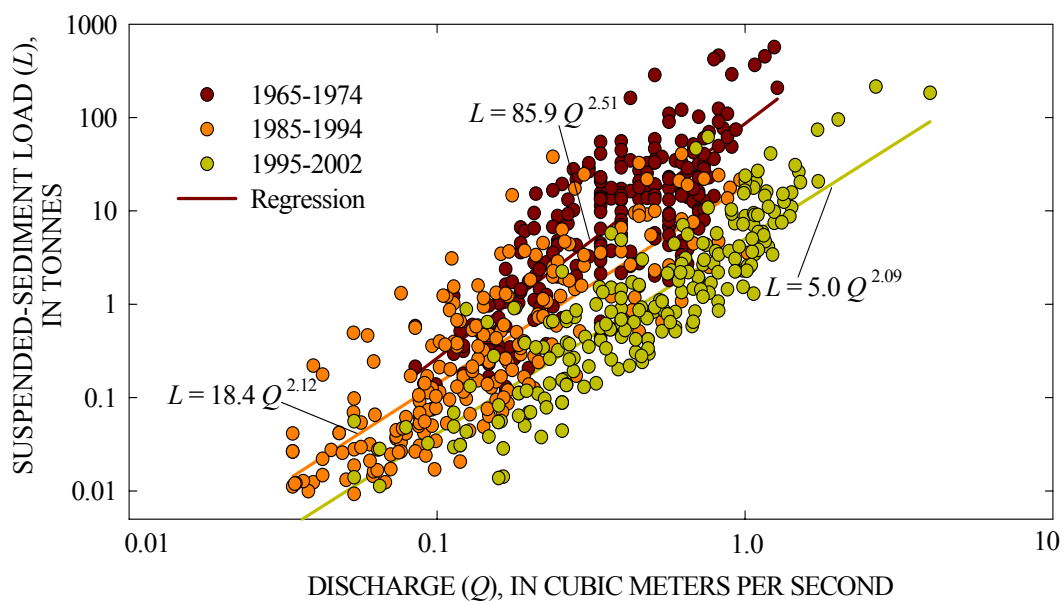


Figure 3-13. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Third Creek (10336698).



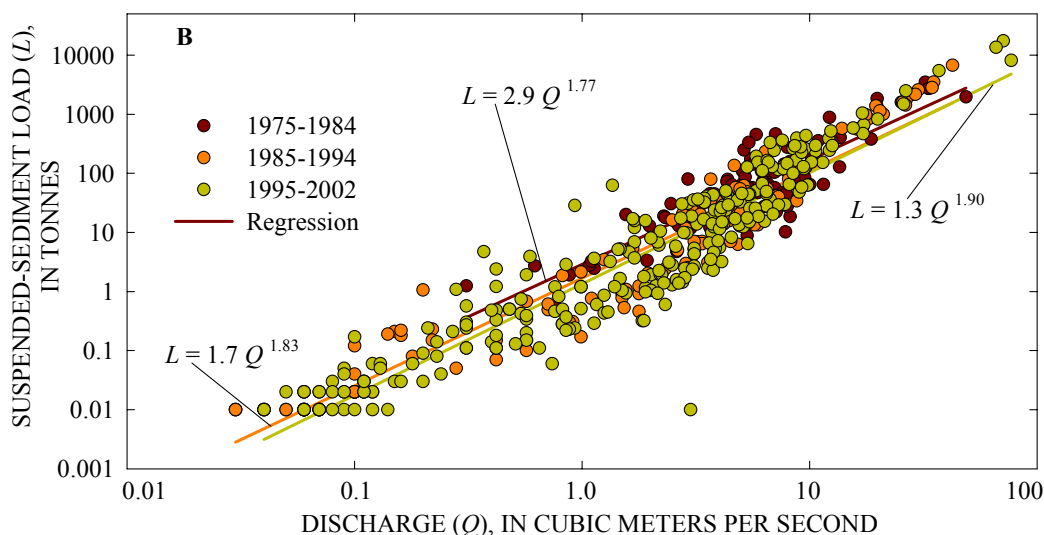


Figure 3-14. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Incline Creek (10336670) (A), and no discernable shift for index station on Blackwood Creek (10336660) (B).

3.10 Summary of Temporal Trends Analysis

Parallel lines of evidence have been provided that show significant reduction in sediment production and delivery from index stations draining developed watersheds in the north quadrant of the basin. Streams such as Third, Incline, and Wood Creeks produce much less suspended-sediment today than they did 30 to 40 years ago. In part this is probably due to natural adjustment processes that cause sediment-transport rates to reduce non-linearly with time following disturbance (Simon, 1992). Erosion control measures have probably also played an important role in these documented reductions in suspended-sediment transport rates. Evidence from other large sediment-producing watersheds such as the Upper Truckee River and Blackwood and Ward Creeks is mixed. Data for the Upper Truckee River does indicate that suspended-sediment transport to Lake Tahoe is decreasing based on annual trends of sediment load per unit of runoff (Tables 3-13 to 3-16). Sediment delivery from Blackwood and Ward Creeks has probably not changed significantly over the past 40 years, in contrast to the increases in loads reported by Rowe *et al.* (2002).

3.11 Relations Between Suspended Sediment Loads and Secchi Depth

The degrading clarity of Lake Tahoe's waters has been quantified through measurements of secchi depth (Figure 1.1) that have conclusively shown a reduction over the past 35 years. With fine-grained suspended-sediment transport loads being a primary suspect of this reduction in water clarity, an attempt was made to correlate fine-grained loadings with secchi depth.

Secchi-depth data were supplied from Reuter (2003, U. California at Davis, written commun.) for two locations in Lake Tahoe. The first disk was located near the shoreline, 0.3 km

southeast of Tahoe Pines, California (close to the mouth of Ward Creek); the second disk was located mid-lake. Both monthly average and annual average secchi-depth data was provided. The duration of available data are summarized in Table 3-19.

Table 3-19. Duration of secchi-disk data.

Disk location name	Longitude	Latitude	Period of record	Duration (years)
LTP (Lake Tahoe Productivity)	39 05.630 N	120 09.000 W	Jul 1967 – Dec 2002	35.5
MLTP (Mid-Lake Tahoe Productivity)	39 09.220 N	120 02.120 W	Jul 1969 – Dec 2002	33.5

After initial data analysis with data from both disks, only the nearshore gage was used for correlation analysis. Regression analyses were carried out between both the actual secchi depth in meters, and the change in secchi depth from the previous record (as an overall decreasing trend in secchi depth was evident over the period of record), for various combinations of suspended-sediment load parameters:

- (1) Annual and monthly data;
- (2) Total load and fine load; and
- (3) Loads for Ward Creek and the sum of loads for Ward Creek, Upper Truckee River and Blackwood Creek.

These streams were selected for inclusion in the analysis because they represent some of the largest sediment contributors to the lake (particularly fine-grained sediments) and with the exception of the Upper Truckee River, are in general proximity to the nearshore secchi disk.

Relations between annual load and secchi depth, and all monthly load and secchi depth did not exhibit strong correlations. However, when the suspended-sediment load data from the spring melt period were isolated, several of the relations with secchi depth were shown to be statistically significant at the 0.05 level.

3.11.1 Suspended-Sediment Loads During May and June

Non-organic material (suspended sediment, as opposed to algae) made up a greater proportion of suspended matter during the spring-melt months of April to July, particularly May and June when snowmelt is greatest (J. Reuter, 2003, U. California at Davis, per. commun.). Additional regression analyses were conducted, therefore, between secchi depth and total monthly loads for these months. Examination of the mean-monthly discharge statistics for major sediment-producing index stations indicated flows consistently peaked in the months of May and June for all gaging stations analyzed (Table 3-20). These months were, therefore, used for spring analysis.

Table 3-20. Average peak flows for May and June.

Stream	Station	Mean Discharge	
		May (m ³ /s)	June (m ³ /s)
Upper Truckee	10336610	8.69	7.30
Blackwood	10336660	3.62	2.86
Ward	10336676	2.60	2.12
Third	10336698	0.56	0.66
Trout	10336780	2.22	2.62
Incline	10336700	0.48	0.44

Although none of the r^2 values were extremely promising, the relation between secchi depth, or change in secchi depth produced several statistically significant relations (Table 3-21). Regression statistics were generally stronger for the change in secchi depth rather than the absolute magnitude of the depth. The number of pairs of data was 25 (degrees of freedom: 24). Using a 95% confidence level (single class), the critical F-value is 4.26. As the calculated F-value is greater than this in all eight cases, all correlations are shown to be statistically significant. Example relations are plotted in Figure 3-15.

Table 3-21. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using the sum of loads during May and June.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	P-value	r^2	F-value	P-value
Sum (Ward, Blackwood, UTR): Total Load	0.249	7.63	0.011	0.412	16.1	<0.001
Ward Creek: Total Load	0.185	5.24	0.032	0.340	11.8	0.002
Sum (Ward, Blackwood, UTR): Fine Load	0.236	7.43	0.012	0.408	16.5	<0.001
Ward Creek: Fine Load	0.266	8.71	0.007	0.390	15.4	<0.001

Table 3-22. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using June data only.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	P-value	r^2	F-value	P-value
Sum (Ward, Blackwood, UTR): Total Load	0.424	16.9	<0.001	0.461	19.6	<0.001
Ward Creek: Total Load	0.357	15.0	<0.001	0.389	17.2	<0.001
Sum (Ward, Blackwood, UTR): Fine Load	0.365	15.5	<0.001	0.391	17.3	<0.001
Ward Creek: Fine Load	0.395	15.6	<0.001	0.507	24.7	<0.001

Regression statistics using the June-load regressions tend to be consistently higher than those using loads for May plus June load (Table 3.22). Perhaps this related to the observation that even though peak loads generally occur in May, it may take some time for the fine-grained sediments to make their way out into the lake, thereby affecting the disks offshore. Again using 95% confidence level (single class), for 24 degrees of freedom, the critical F-value is 4.26. With the calculated F-values for each June regression being greater than the critical value, in all eight cases there is no reason to reject that hypothesis that there is a significant relation between the pairs of variables shown in Table 3-22. Two examples of this are shown in Figure 3-16. It is also interesting to note that relations for fine sediment emanating from Ward Creek have among the strongest statistical significance of all those attempted owing to the creek's proximity to the nearshore disk.

3.11.2 Discussion

It appears that low and moderate flows do not have a strong influence on secchi depth/change in secchi depth, as there is consistently considerable scatter in values for these variables when suspended loads are low. However, large snowmelt discharges causing large suspended-sediment loads, subsequently have been observed to cause notable declines in secchi depth. Because of the great inherent complexities in delivery and mixing processes that are masked by these simple regression techniques, they are probably conceptually accurate but quantitatively, contain a reasonable degree of uncertainty. Still, the fact that the tested regressions are statistically significant beyond the 0.05 confidence level indicate that:

- (1) suspended-sediment loads, particularly those during the spring melt season can be used as an indicator of lake clarity, and
- (2) maintenance of the long-term monitoring station at the mouth of Ward Creek (10336676) that includes sampling for suspended-sediment and suspended particle-size distribution is justified as a basis of comparison with secchi depth data (Figures 3-15b and 3-16b).

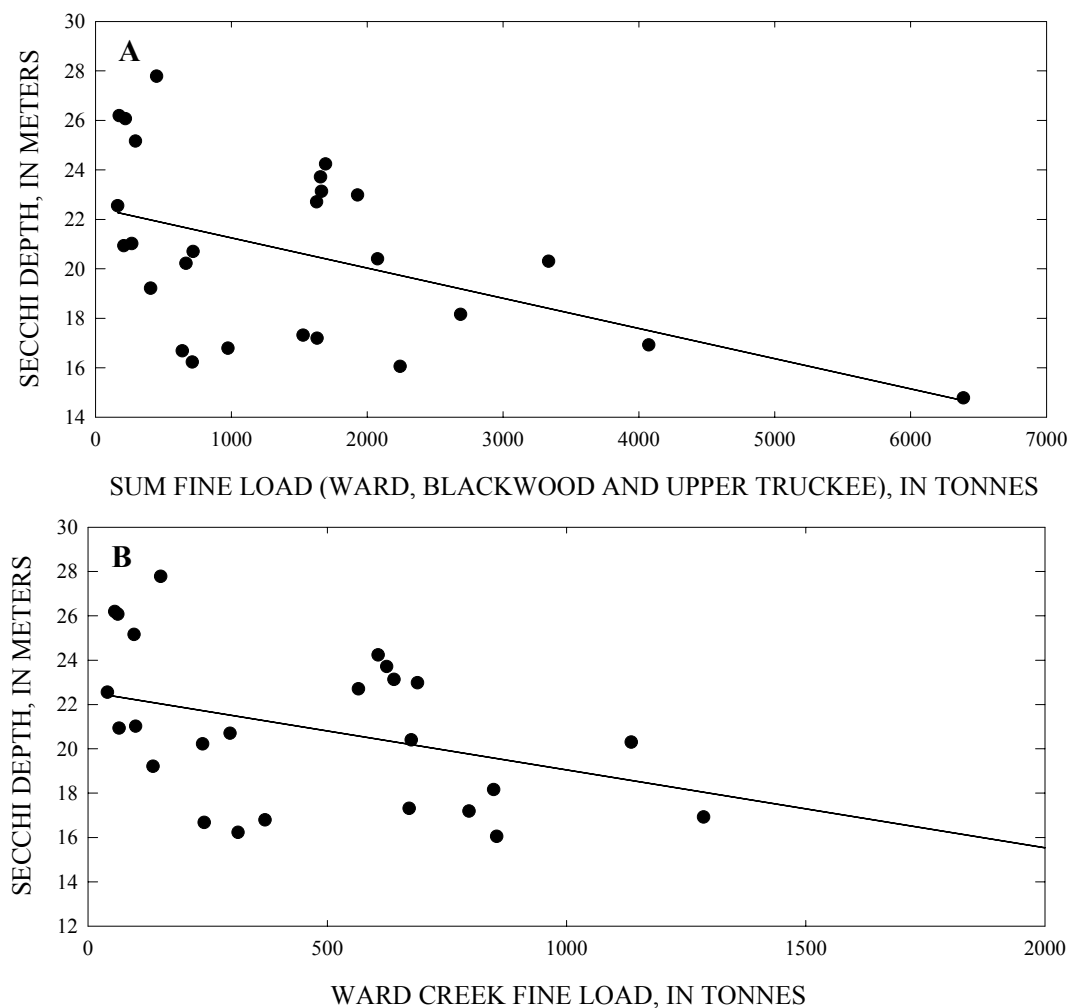


Figure 3-15. Linear regressions between fine suspended-sediment load and secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).

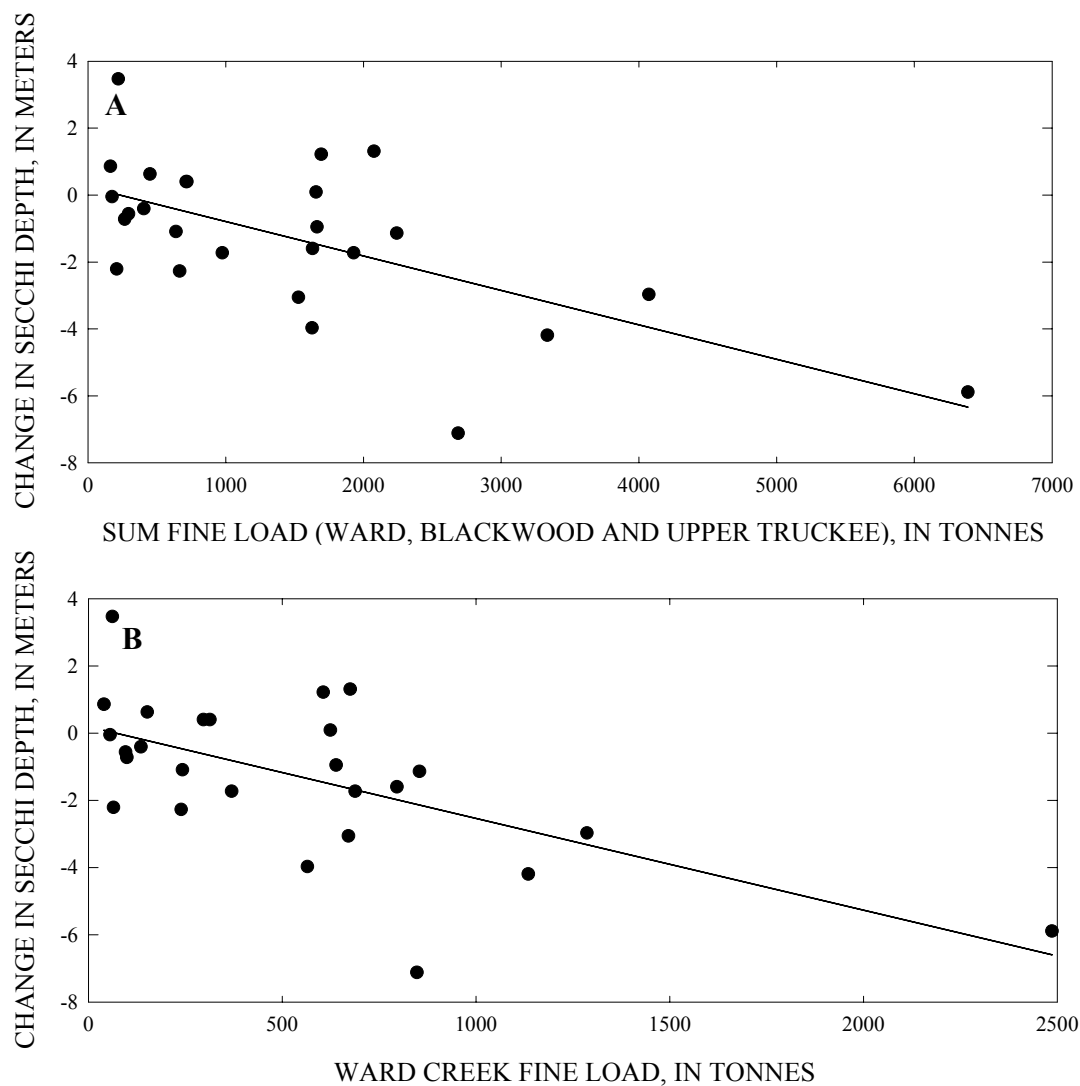


Figure 3-16. Linear regression between fine load and change in secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).